Technology Development for Aircraft Noise Alleviation

Engine Noise Reduction Research

presented to
The Hiller Aviation Museum
December 9, 2000

by
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Aircraft Noise - Why are we working on it?

- **Quality of Life near Airports**
- **Allow Aircraft & Engine Manufacturers Meet Government and Local Noise Regulations**
- **Provide Competitive Advantage for U.S. Industry**

OUTLINE

- Certification
- Turbofan Noise Sources
- Recent Engine Noise Reduction Research
- Future Directions

Certification

Aircraft Noise Regulations

1969 - FAA issues noise rules for new subsonic aircraft (Stage 2)
Federal Air Regulation "FAR 36"

1973 - Stage 2 noise limits extended to all subsonic aircraft
produced after 1973

1976 - Stage 2 noise limits extended to all subsonic aircraft operating in the U.S.

1977 - FAA issues "Stage 3" noise limits for new subsonic aircraft

1978 - Stage 2 limits apply to supersonic aircraft, except
Concords flying before 1980

1986 - FAA issues notice to extend Stage 3 limits to all new supersonic transports

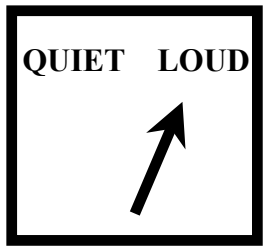
2000 - Phase-out of all Stage 2 aircraft in U.S. (except Concorde at specific airports)

2001 - Possible "Stage 4" noise limits announced through the International
Civil Aviation Organization (ICAO)

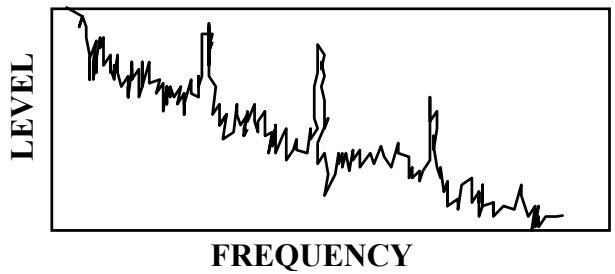
Effective Perceived Noise Level (EPNL)

- Quantifies Annoyance of Aircraft Flyover
- Used For Certification
- Available Through FAA For Each Aircraft & Engine Combination
  http://www.aee.faa.gov/aee-100/aee-110/AC/AC_all.htm
- Expressed as "EPNdB" by Integrating:

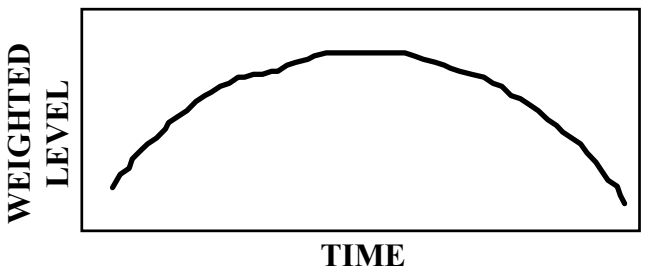
Level



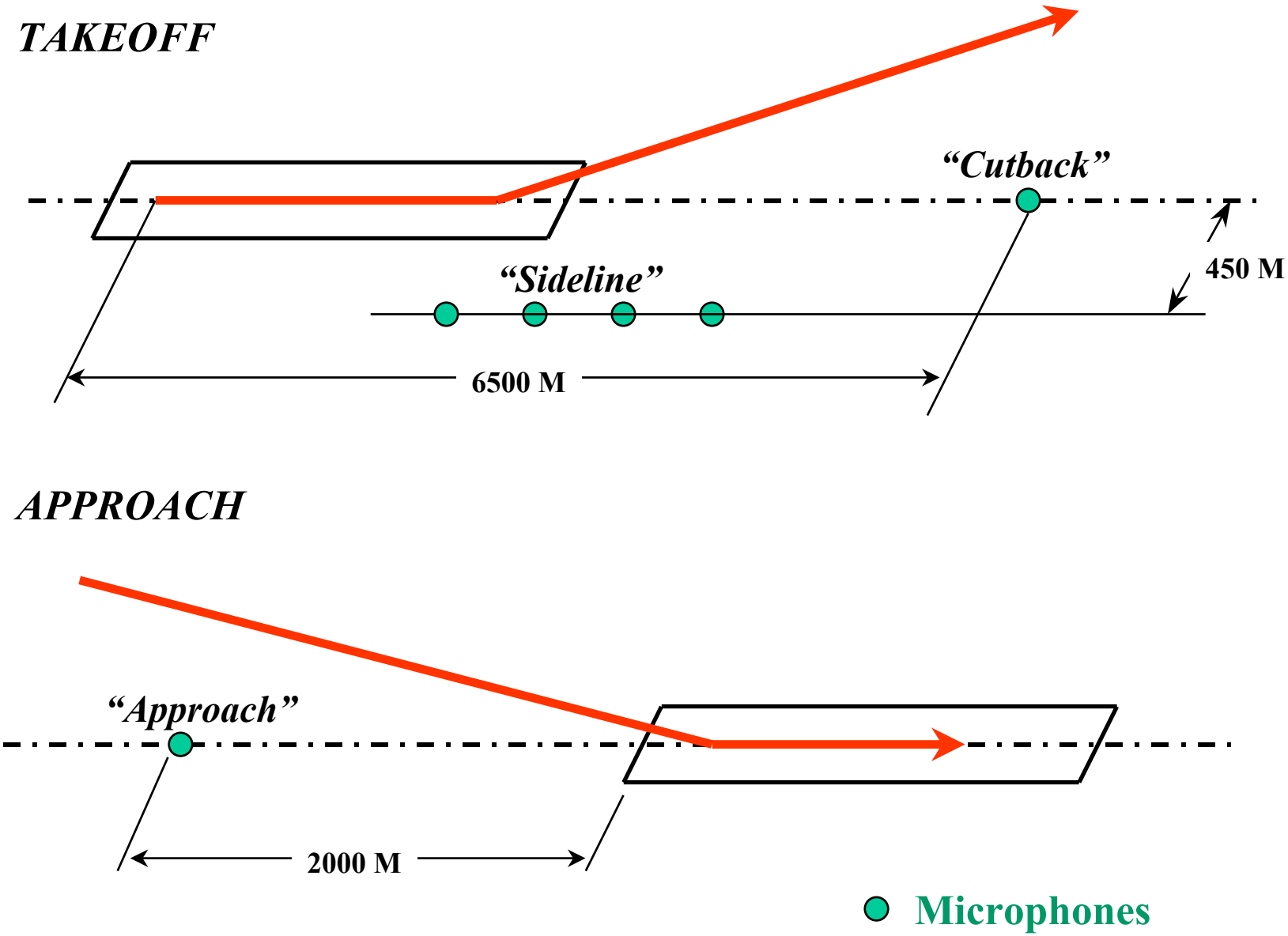
Frequency & Tone Content



Duration (Time of Flyover)



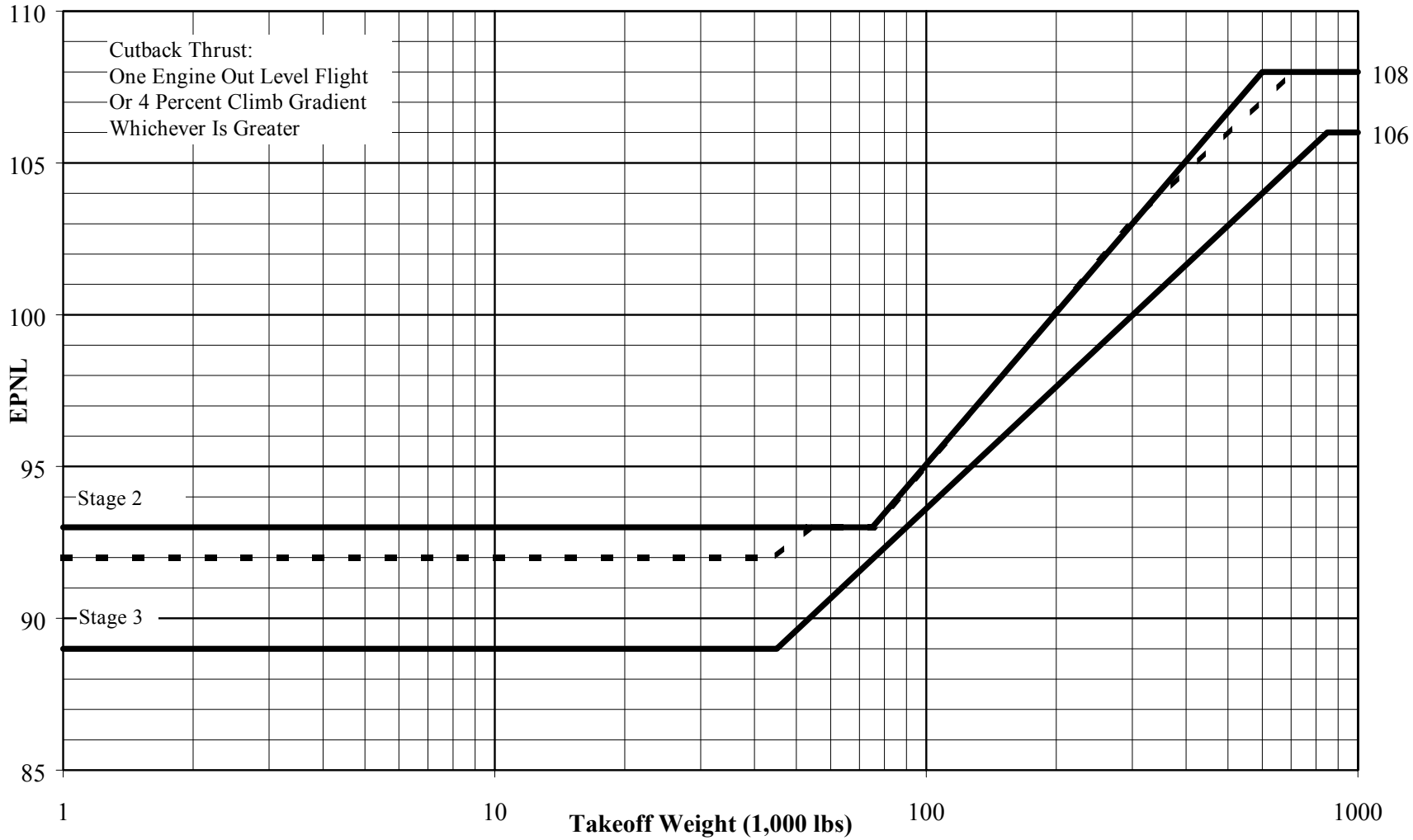
Certification Measurement Locations



FAA Certification Noise Levels

Takeoff - 4 Engines

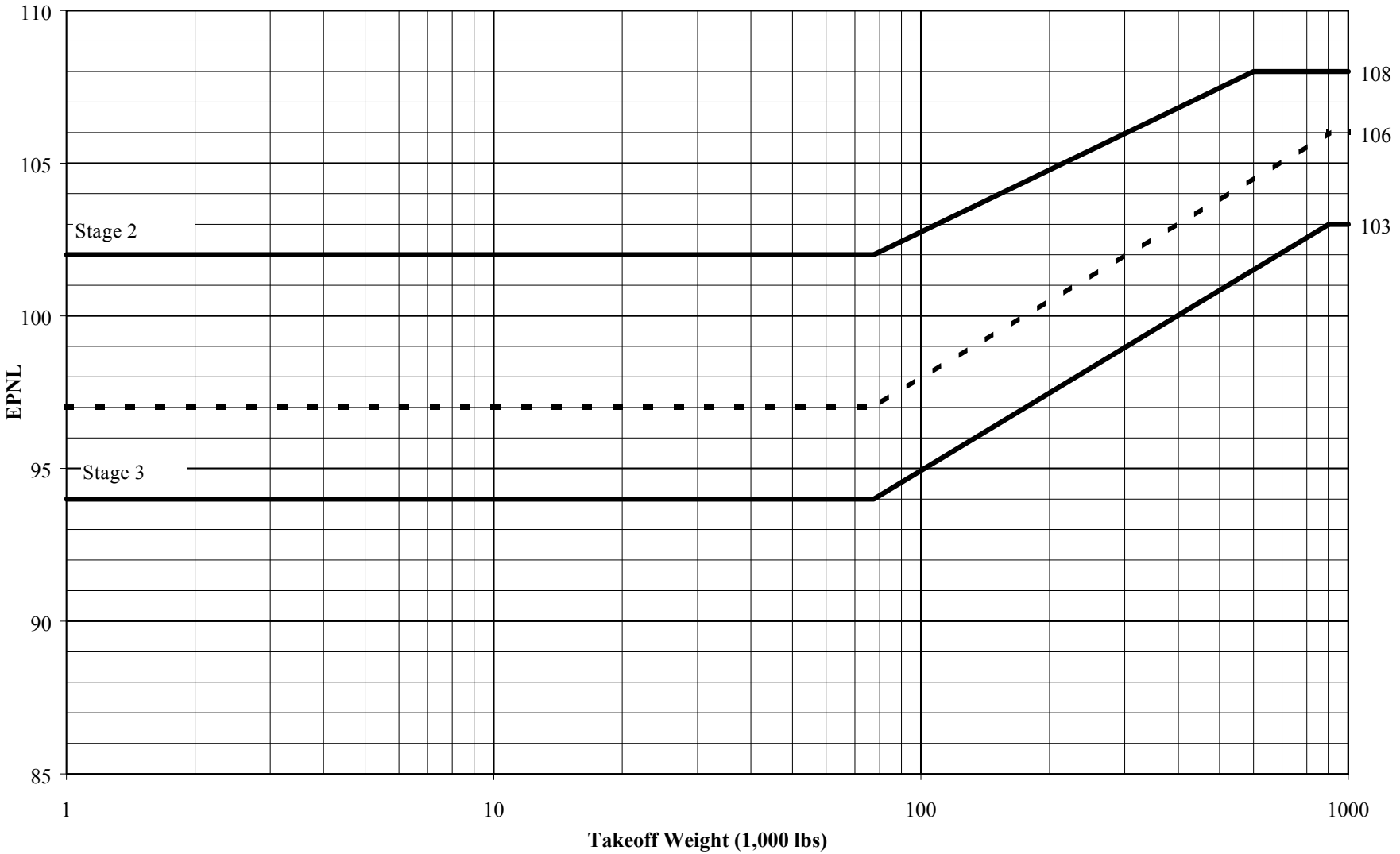
NOISE CERTIFICATION REQUIREMENTS - JET AND TRANSPORT AIRPLANES



FAA Certification Noise Levels

Sideline

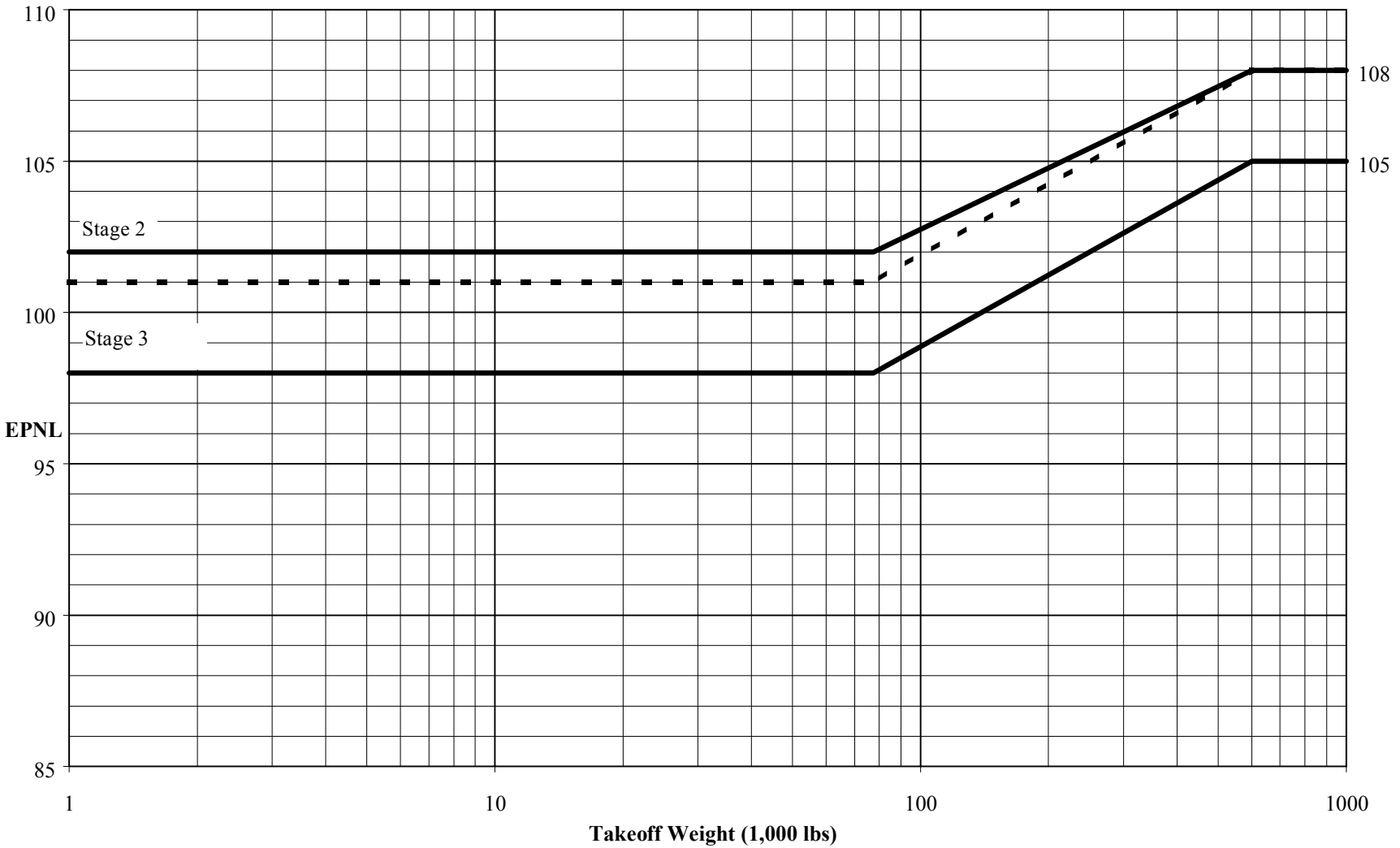
NOISE CERTIFICATION REQUIREMENTS - JET AND TRANSPORT AIRPLANES



FAA Certification Noise Levels

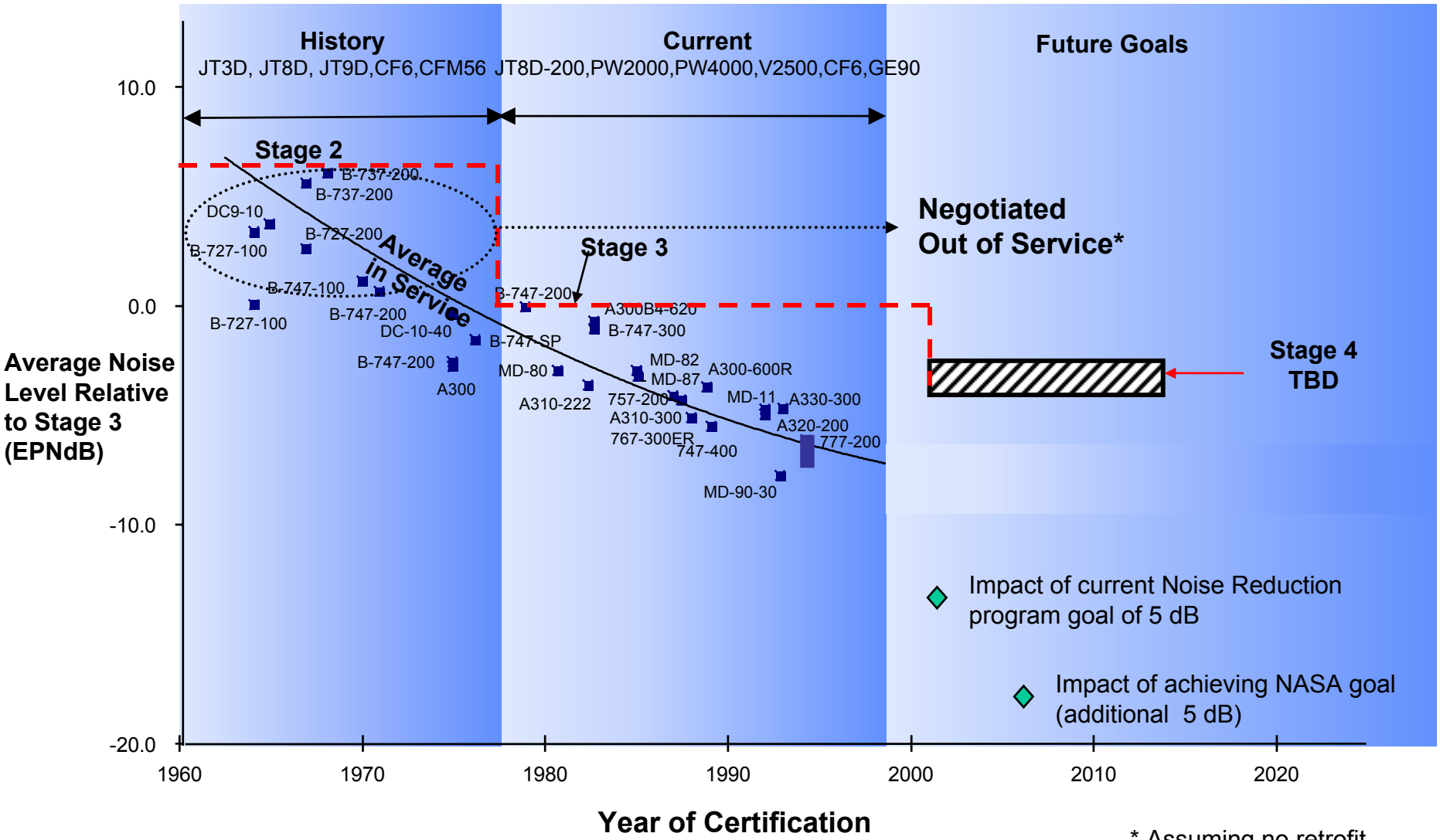
Approach

NOISE CERTIFICATION REQUIREMENTS - JET AND TRANSPORT



Concorde

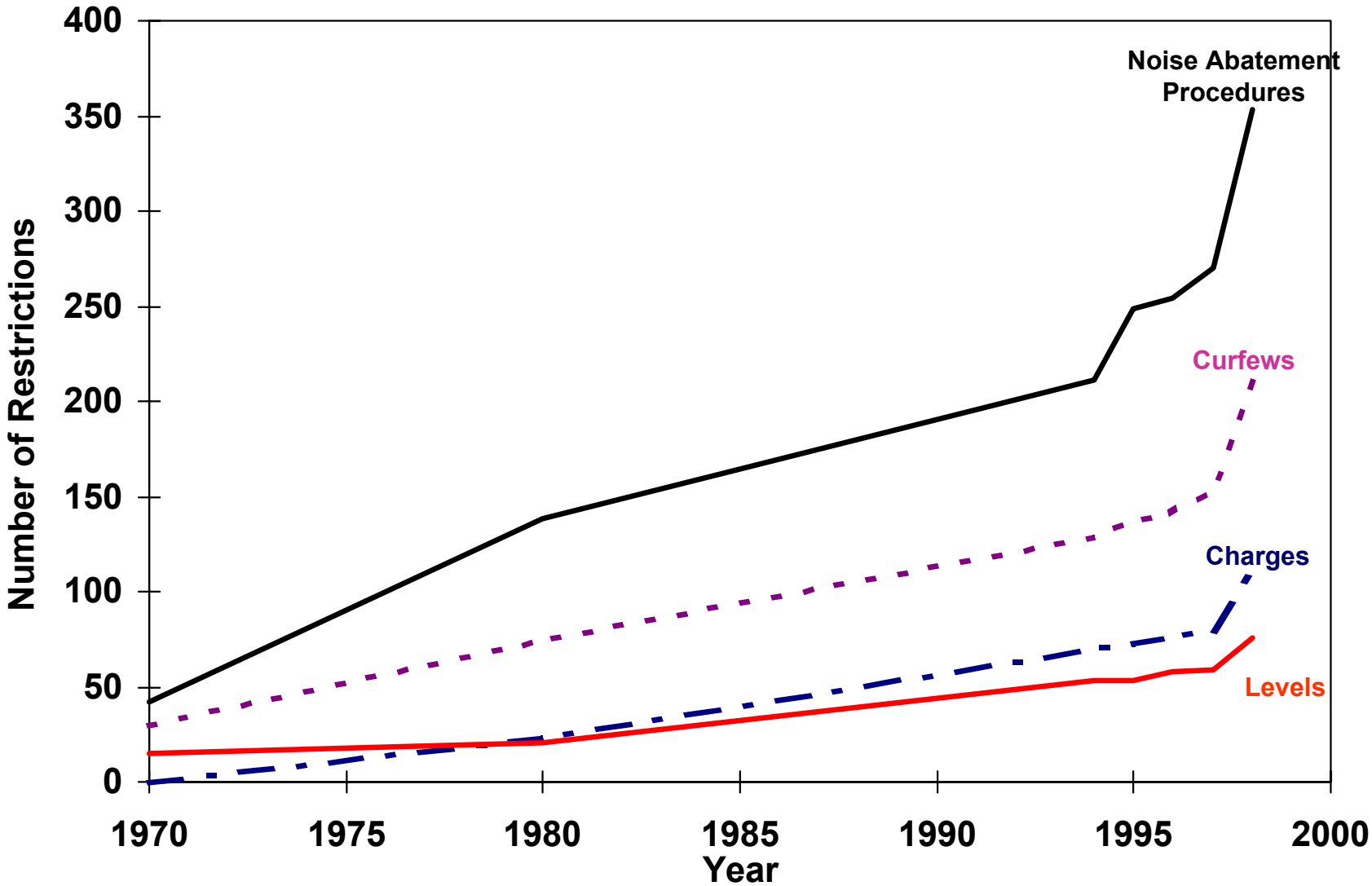
New Technology Enables Aircraft To Meet Future Requirements



* Assuming no retrofit

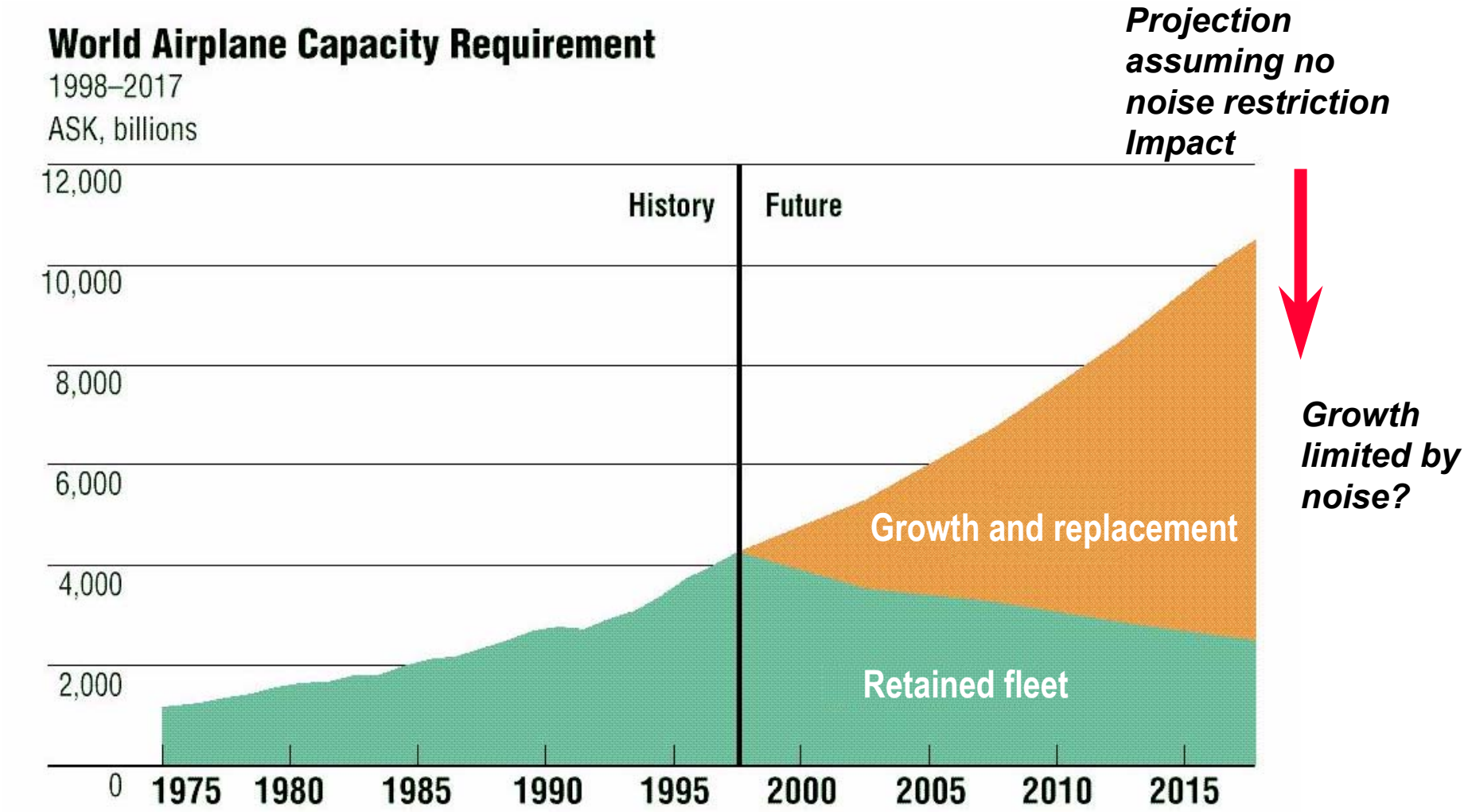
Noise Restrictions Continue to Grow

Number of Airports in Database: 591



Source: David H. Reed, Manager of Noise Technology, Boeing Commercial Airplane, 1998

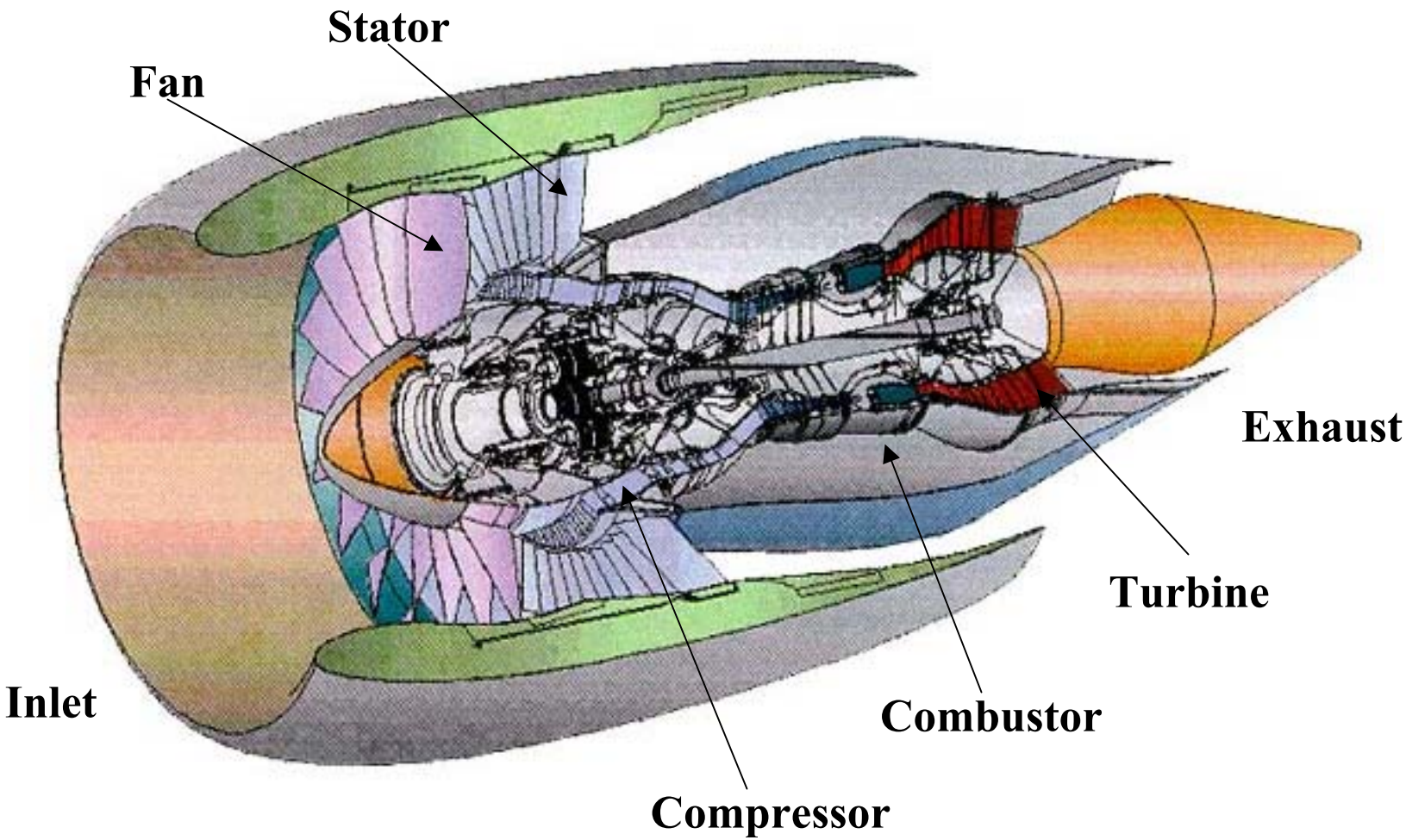
Noise Restrictions may Hinder Aviation Growth Unless Significant Progress is Made



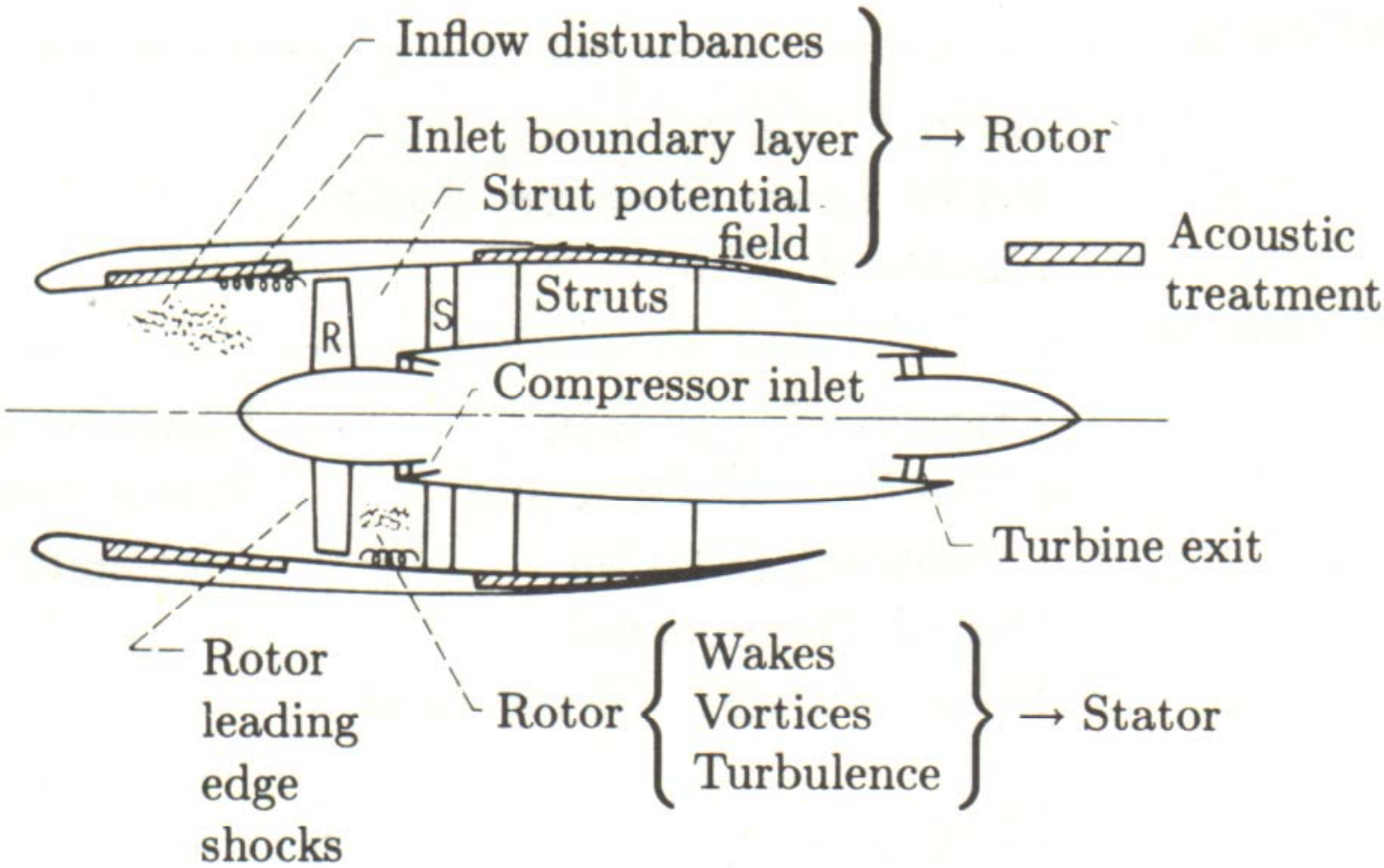
Source: David H. Reed, Manager of Noise Technology, Boeing Commercial Airplane, 1998

Turbofan Noise Sources

Pratt & Whitney's PW8000 Turbofan Engine (Conceptual)

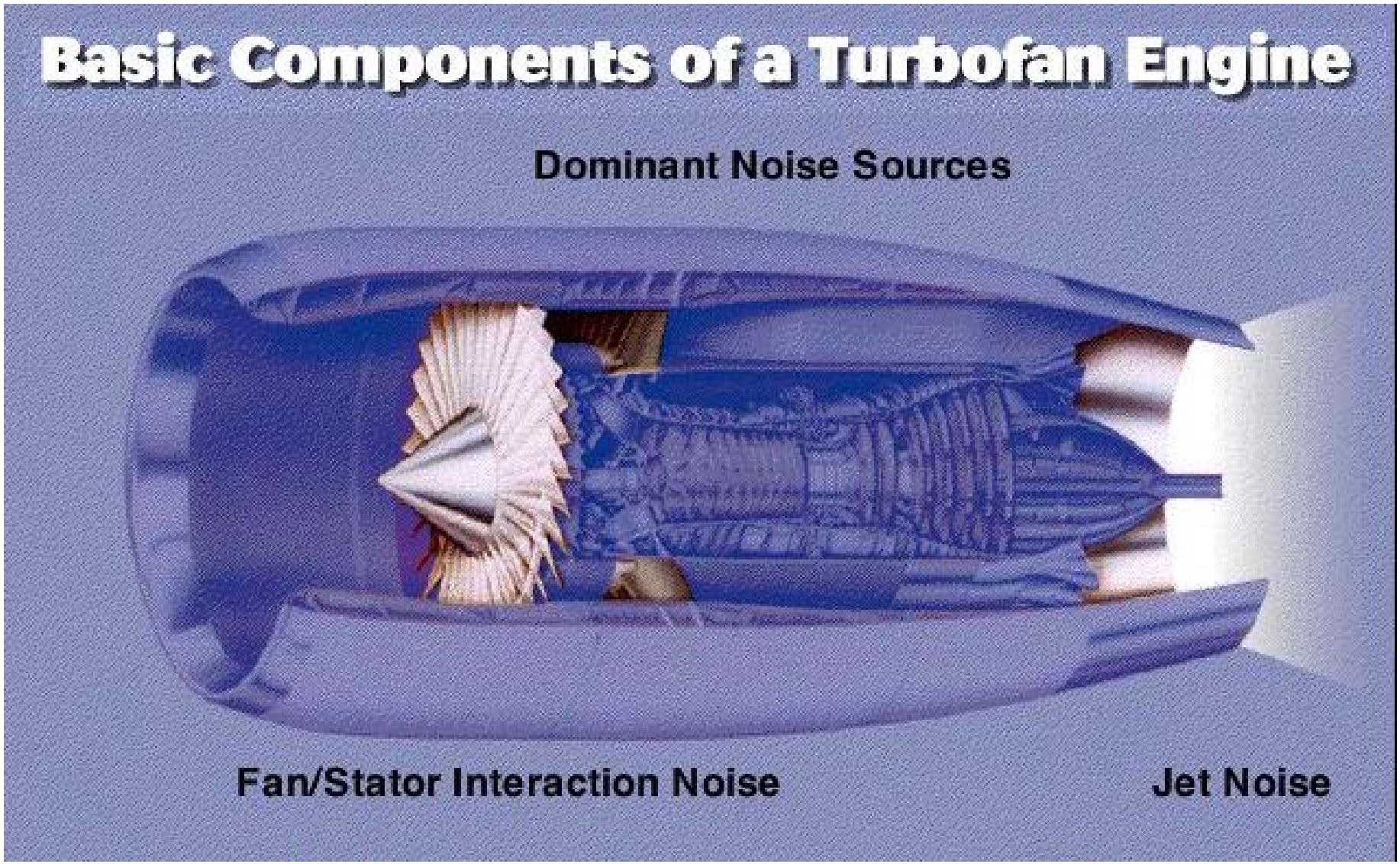


Turbofan Engine Noise Generation Mechanisms

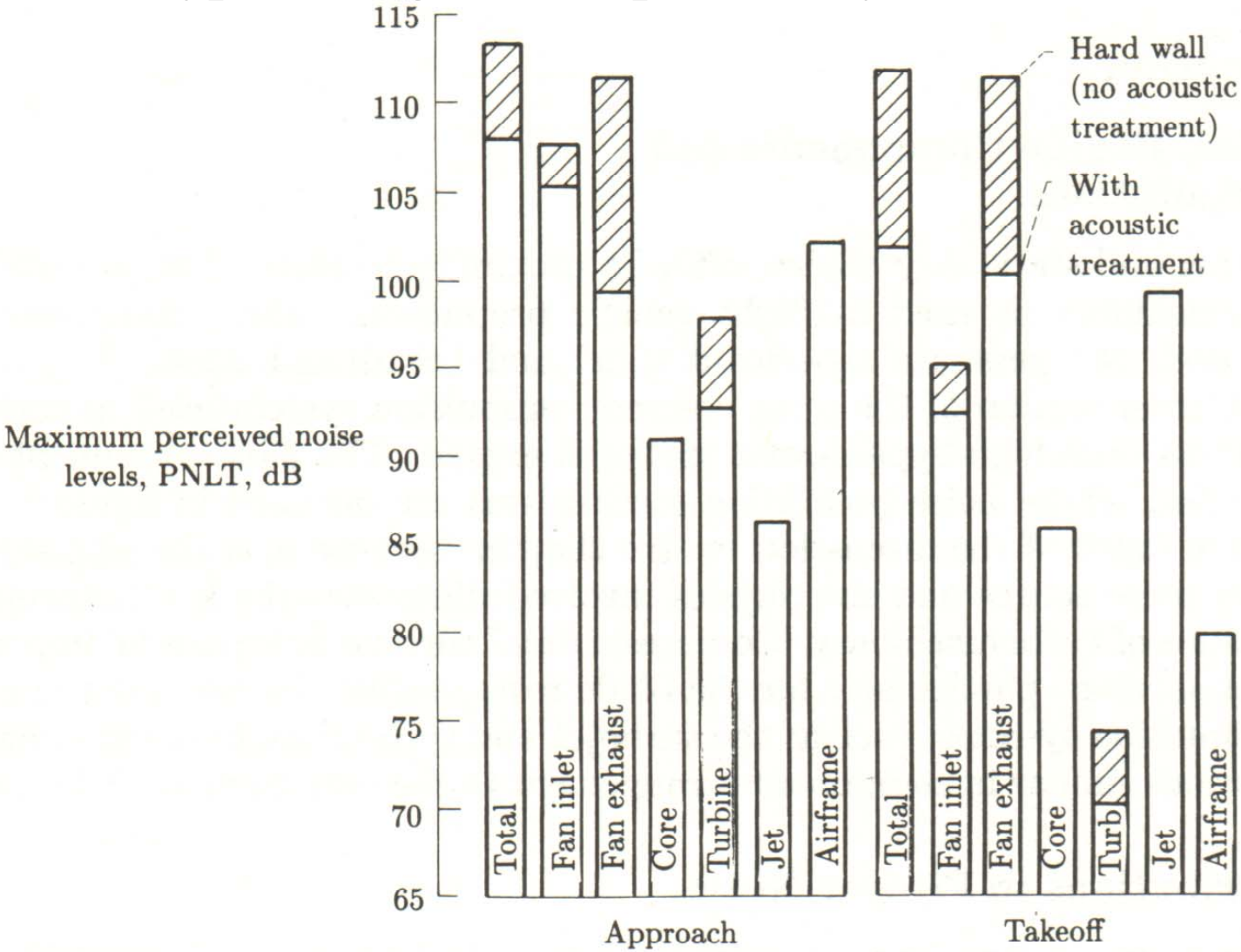


Reference: Hubbard, et. al.: *Aeroacoustics of Flight Vehicles - Theory and Practice, Volume 1: Noise Sources*, NASA RP 1258, 1991.

Emphasis of Research in the 1990's



Typical Engine Component Flyover Noise Levels



Reference: Owens, R.E.: *Energy Efficient Engine Performance System - Aircraft Integration Evaluation*, NASA CR-159488, 1979.

Recent Engine Noise Reduction Research

- Fan Noise
- Nacelle Aeroacoustics
- Jet Noise

Turbofan Noise Reduction Research

Engine Noise Reduction

NASA Glenn Research Center
Contact: Dennis Huff
Dennis.L.Huff@grc.nasa.gov

GOAL: Provide technology for lowering engine source noise while maintaining high performance for advanced turbofan engines.

Objective: 6 dB engine noise reduction relative to 1992 technology

Nacelle Aeroacoustics

NASA Langley Research Center
Contact: Joe Posey
j.w.posey@larc.nasa.gov

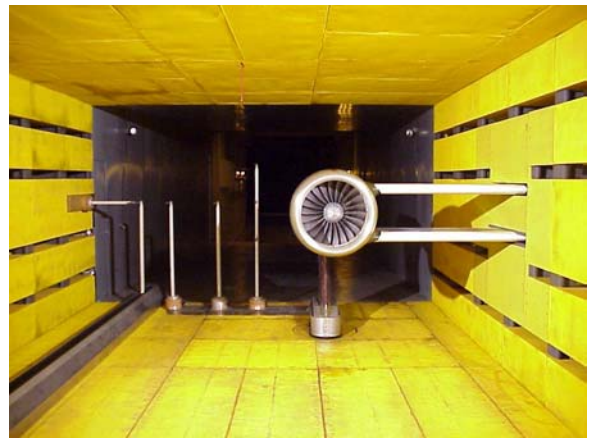
GOAL: Provide technology to increase the effectiveness of the nacelle in absorbing, canceling, or redirecting turbomachinery noise.

Objective: Achieve 50% increase in nacelle suppression effectiveness relative to 1992 technology.

Fan Research in the NASA 9'x15' Wind Tunnel

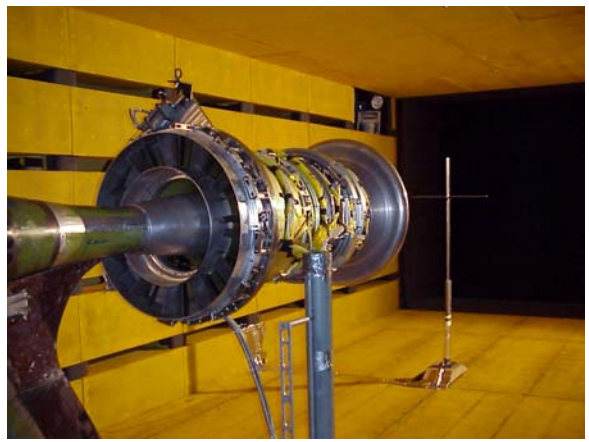
Acoustics
Inlet/Aft Noise Separation

Aero & Structural Dynamics

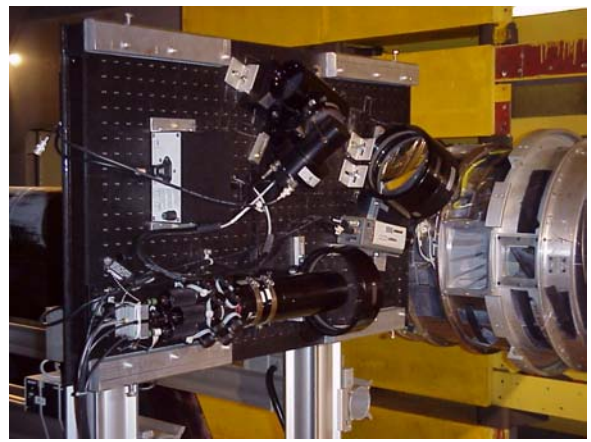


Source Diagnostics
Rotor-Alone Configuration

Acoustics
Sideline Microphone Traverse



Fan Mapping
Variable Area Nozzle



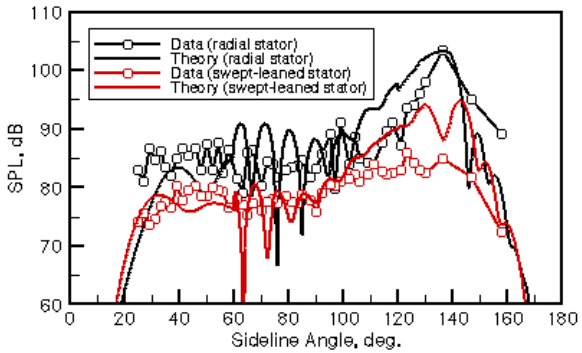
Flow Measurements
Laser Doppler Velocimetry

Fan Noise Prediction

Tone Noise

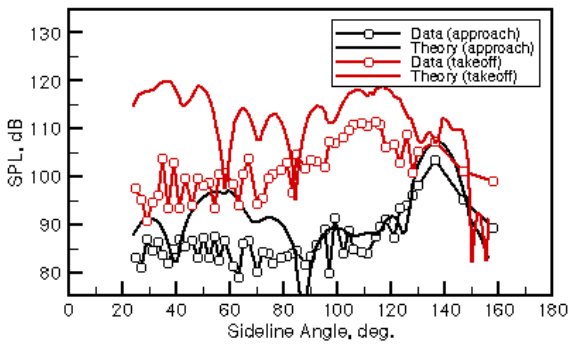
V072/Eversman Codes

Inlet/Stator/Exhaust



TFaNS

Inlet/Fan/Stator/Exhaust



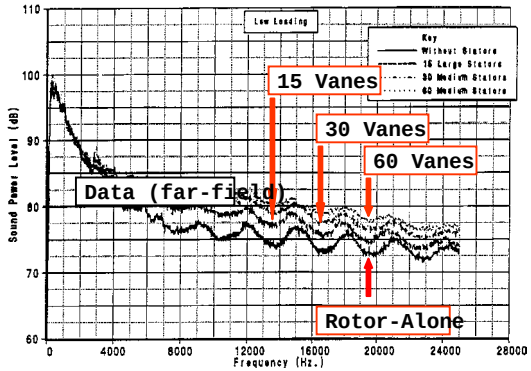
Excellent Results for Variable Geometry with Low-Speed Fans (Rotor/Stator Noise)

Still Need Improvements for High-Speed Fans (Rotor Self Noise, Reflection/Transmission)

Broadband Noise

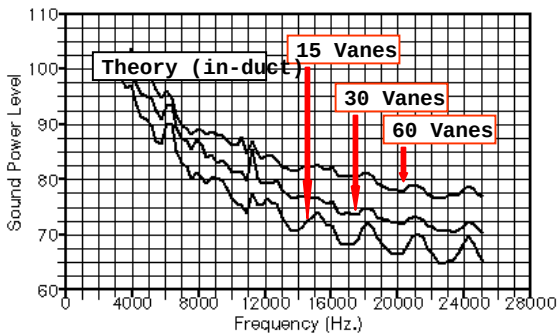
Boeing 18" Fan

Far Field Data



Envia Broadband Analysis

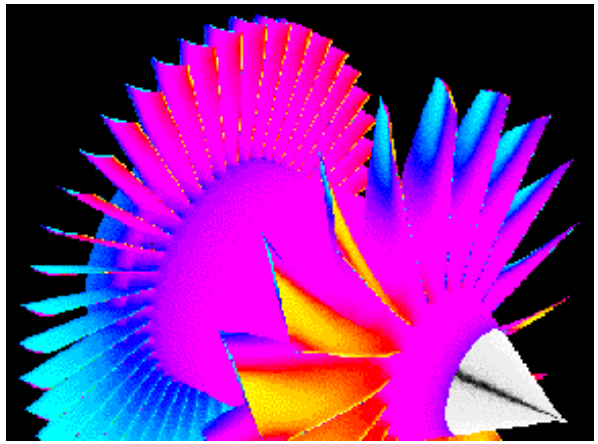
In-Duct Power Levels



Data from NASA/Allison 22" Fan

Fan Noise Reduction Research

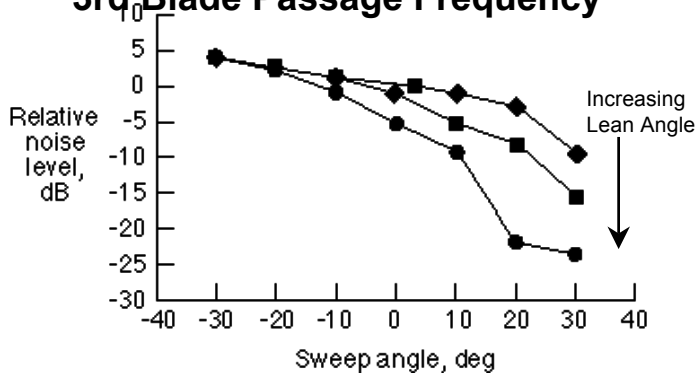
Design of Low-Noise Stators Using Aeroacoustic Analyses



- Numerical predictions indicate that interaction tones can be reduced to broadband noise levels of a fan
- Optimal sweep/lean designs predicted to meet 3 EPNdB fan noise reduction
- 22 inch model fan hardware tested in 9 x 15 Wind Tunnel, results verify predictions

Predicted Dominant Fan Tone

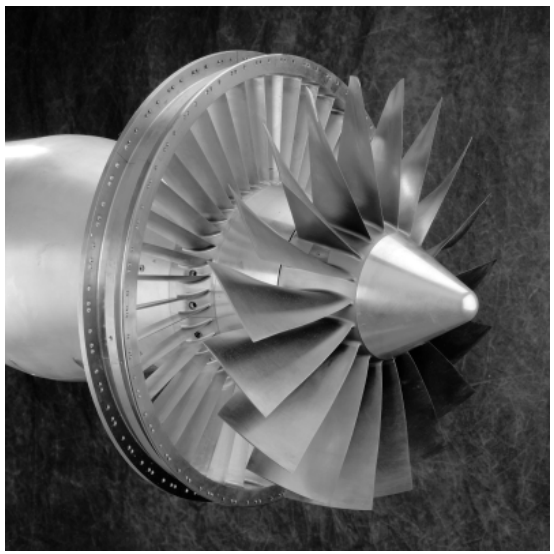
3rd Blade Passage Frequency



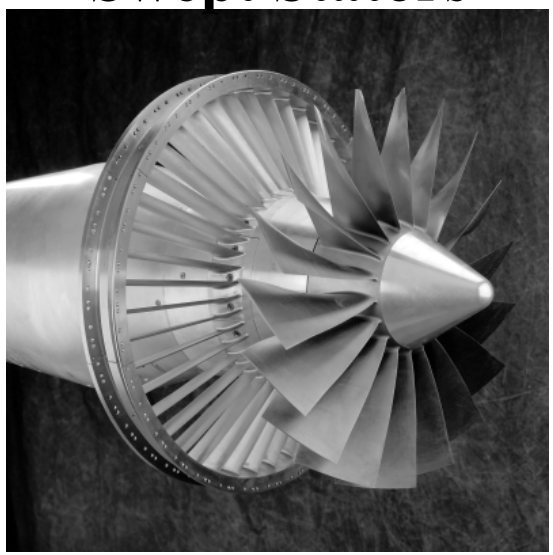
Fan Noise Reduction Research

1996 NASA/Allison Swept & Leaned Stator Test

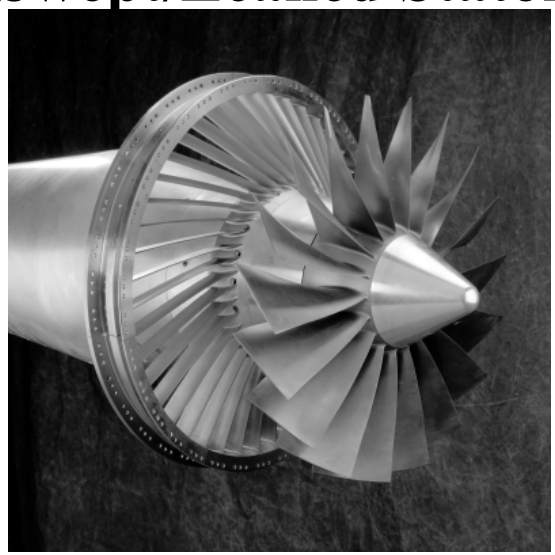
Baseline



Swept Stators



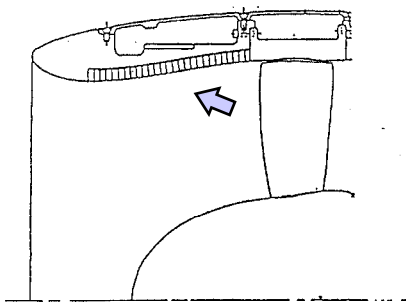
Swept/Leaned Stators



Fan Noise Reduction Research

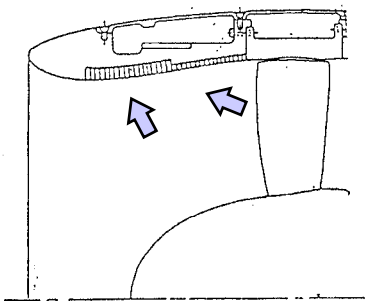
1996 NASA/Northrop Grumman Active Noise Control Fan Test

Uniform Passive



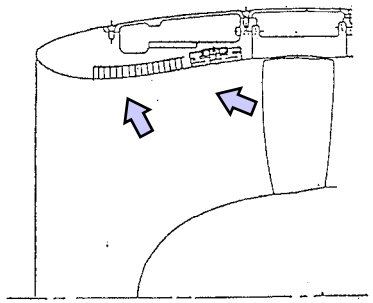
Near Grazing Incidence Fan Noise; Modest Overall Attenuation.

Two Segment Passive

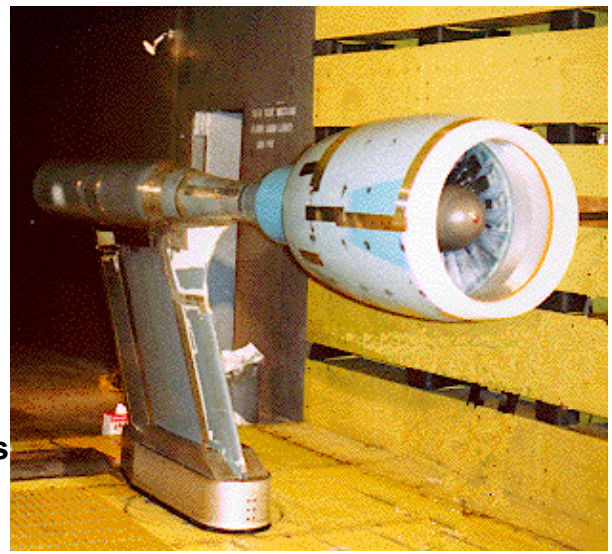


Initial Segment Scatters Modes into Higher Order Radial Modes.
Limited Bandwidth of Attenuation Since Liner is Efficient only near Design RPM.

Hybrid Active/Passive



Initial Active Control Segment Compensates for Changing Parameters Resulting from Mode Mixture Variations with Fan Speed. High Band-width of Attenuation.

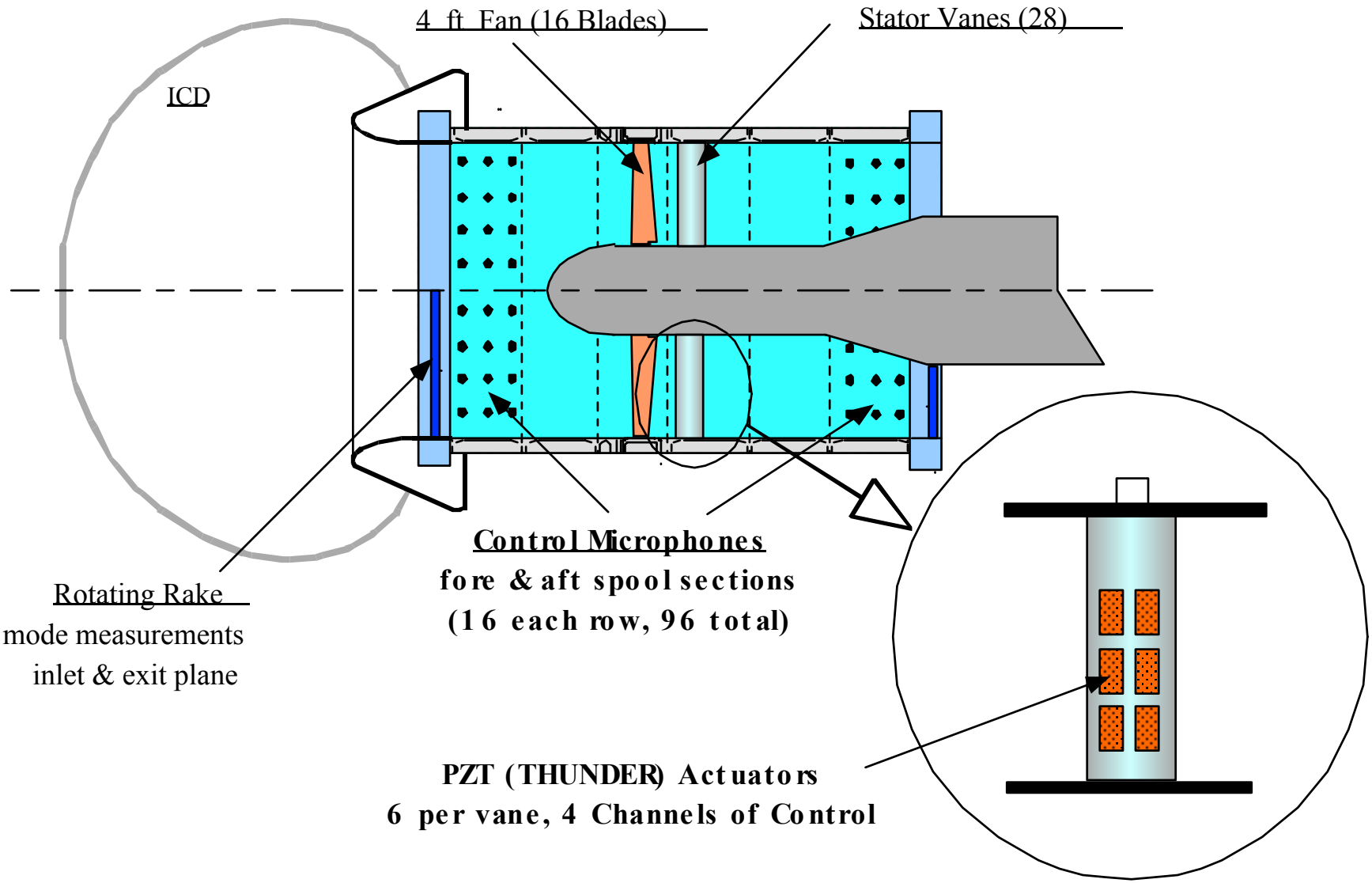


Northrop Grumman Hybrid Active/Passive Liner Installed in the NASA ADP Fan Rig at the NASA LeRC 9'x15' Wind Tunnel

- Superior Performance Relative to Conventional Uniform Passive Liners Over Extended Fan Speeds
- 3 to 10 dB Attenuation Increase Over Uniform Passive Liners for ADP Fan over the Speed Range of 5200 to 6000 RPM

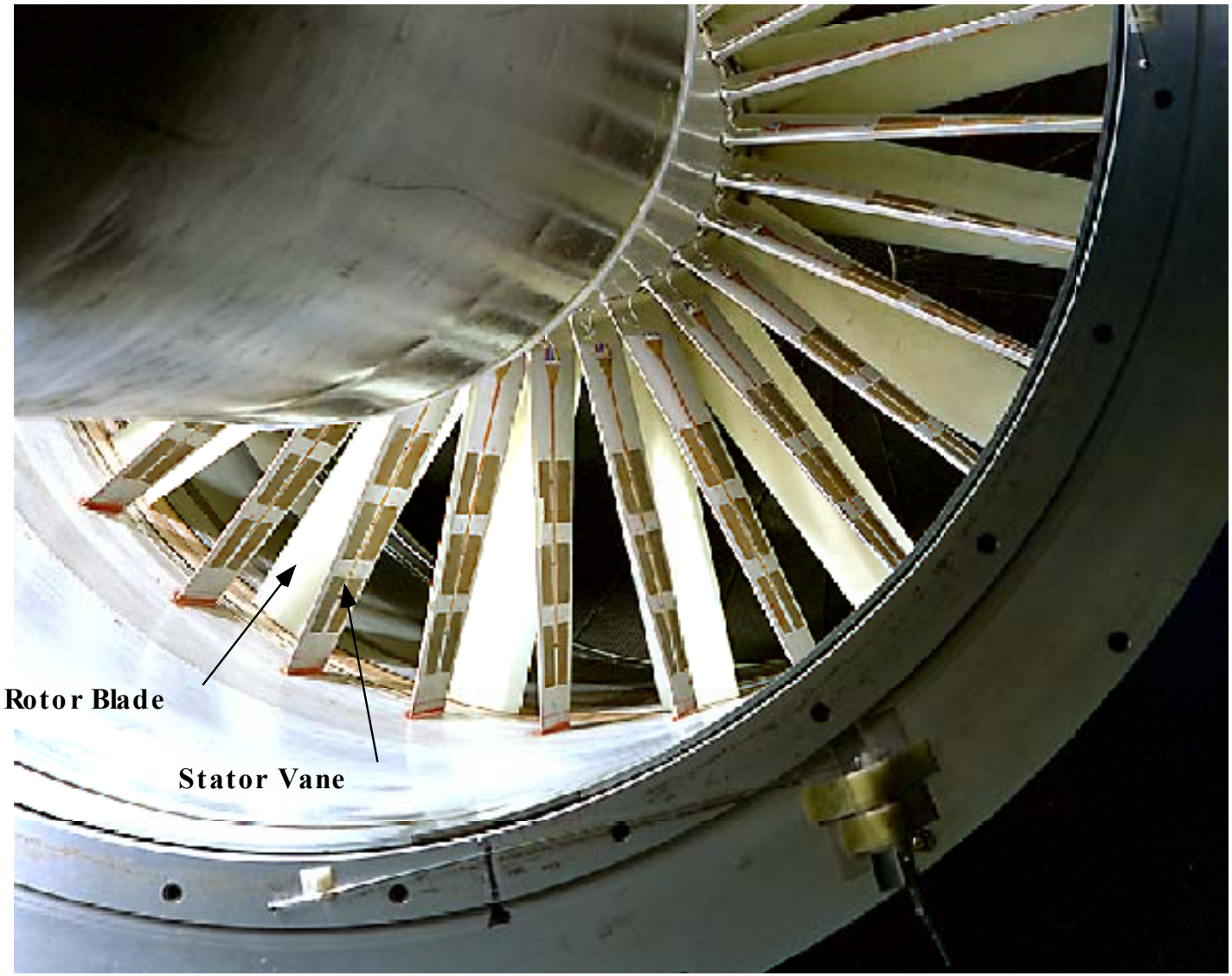
Fan Noise Reduction Research

1998 NASA/BBN Active Noise Control Fan Test



Fan Noise Reduction Research

1998 NASA/BBN Active Noise Control Fan Test



FIRST ENGINE APPLICATION OF ROTATING MICROPHONE

- World's first successful rotating microphone measurement of fan tone modes on engine
- Provides valuable diagnostic information to determine engine noise source mechanisms
- Application of technology developed at NASA Glenn in early 1990's for model scale fans
- Work supports engine validation tests being performed by AlliedSignal for the AST Noise Reduction Program

Rotating Microphone Mounted On Inlet

First Rotating Microphone Developed For Model Fan Tests in NASA Glenn's 9'x15' Wind Tunnel in 1991

AlliedSignal TFE731-60 Engine, San Tan Test Facility

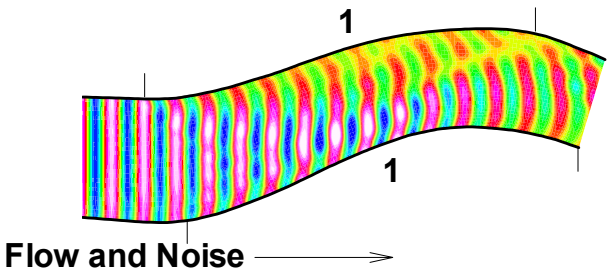
Nacelle Aeroacoustics Noise Reduction Research

1999 NASA/P&W/Boeing "Scarfed" Inlet on PW4098 Engine

FED399428

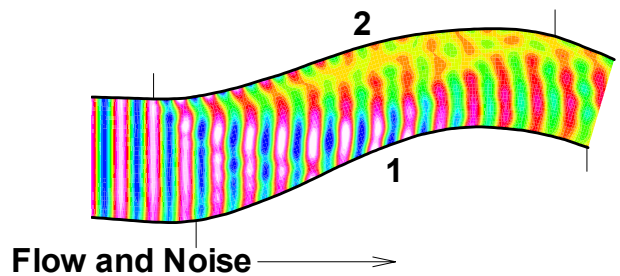
Optimized Segmented Aft Fan Duct

One Segment



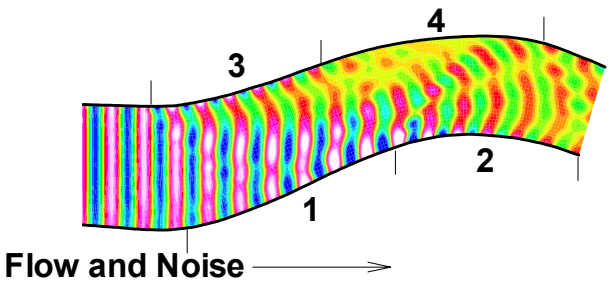
Attenuation = 7.1dB

Two Segment



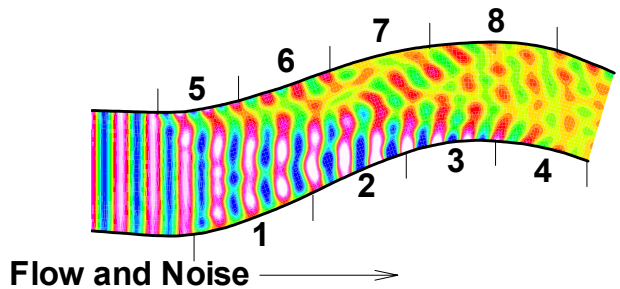
Attenuation = 8.6dB

Four Segment



Attenuation = 12.0dB

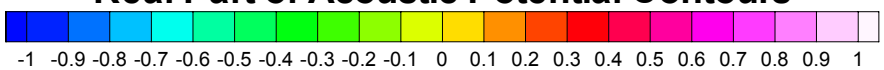
Eight Segment



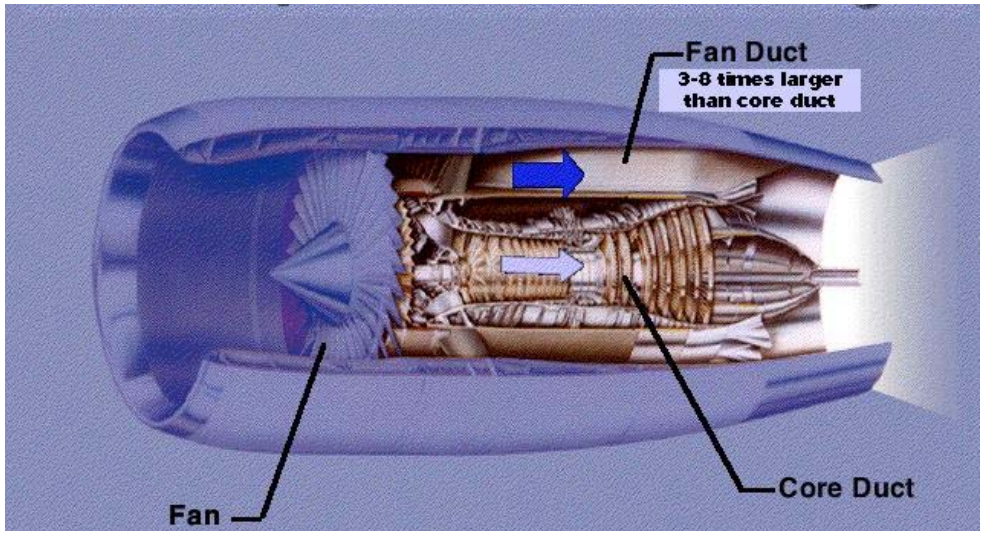
Attenuation = 16.3dB

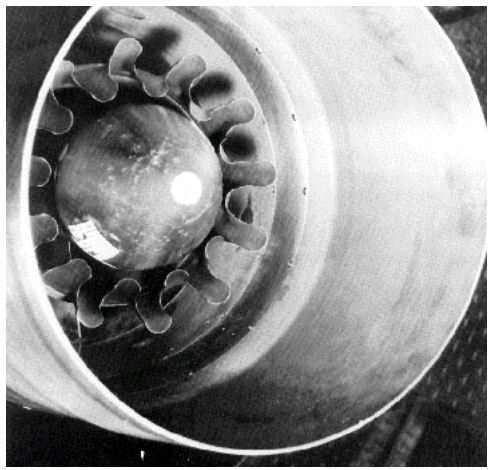
Plane Wave Source
Frequency = 4kHz
Initial Mach = 0.5

Real Part of Acoustic Potential Contours

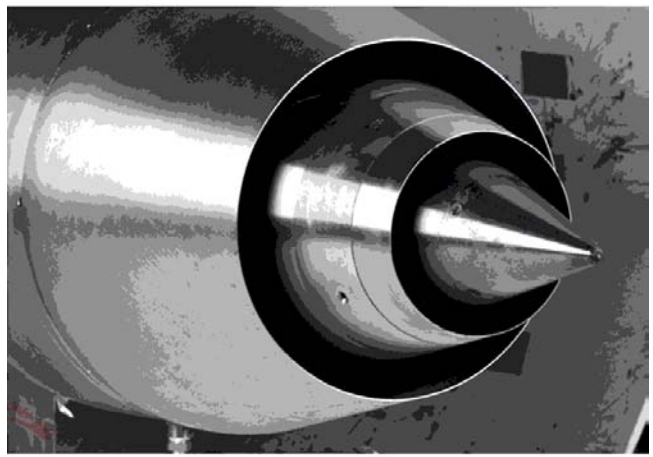


Jet Noise Research - Subsonic Applications





Internally Mixed Flow Exhaust



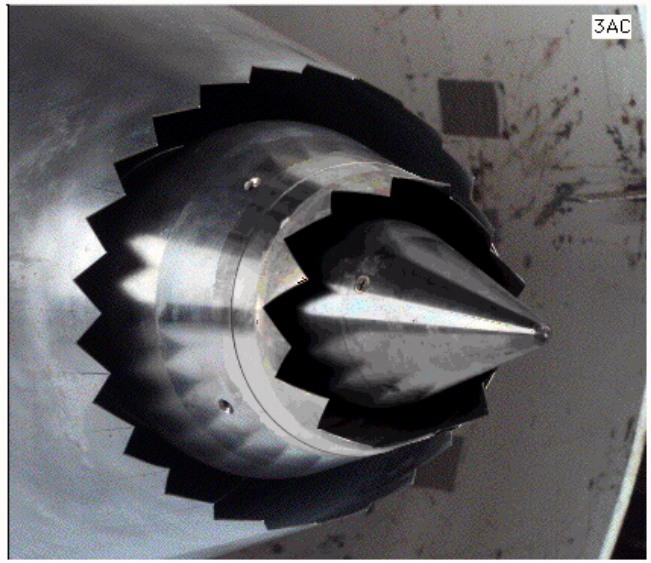
Separate Flow Exhaust

Jet Noise Reduction Research

1997 NASA/GE/P&W Separate Flow Nozzle Test

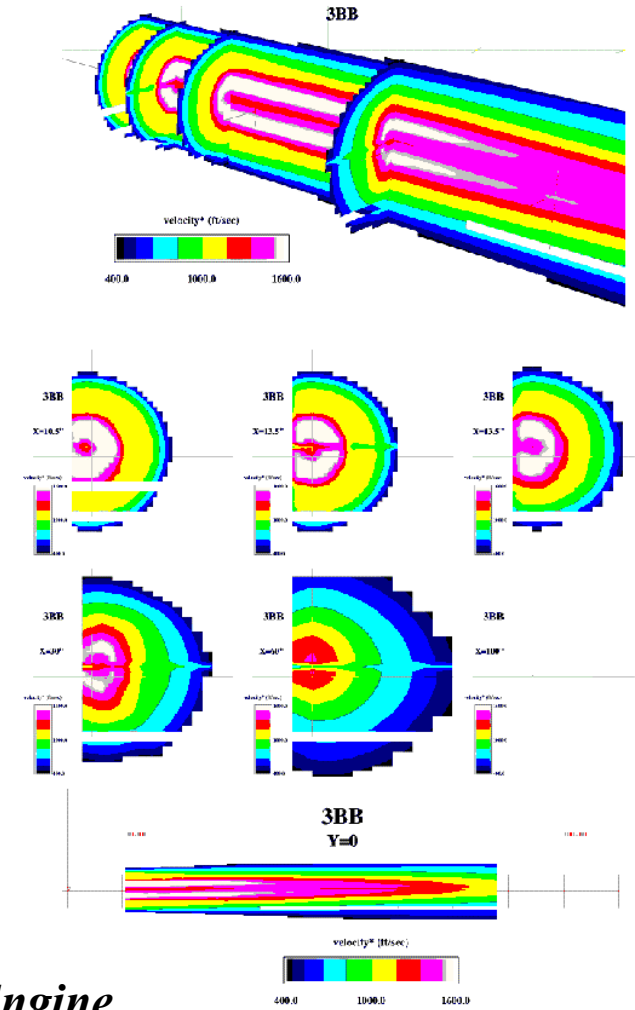
Nozzles of the Future

Fan Chevrons with Core Alternating Chevrons



GE CF34 Engine

Flow Field Measurements



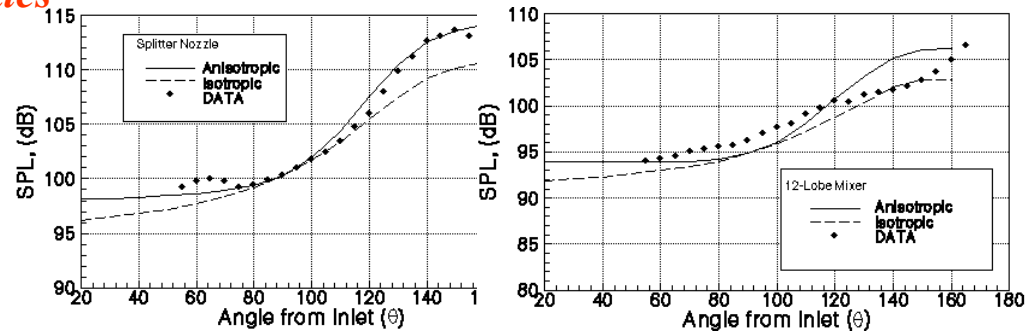
Jet Noise Prediction

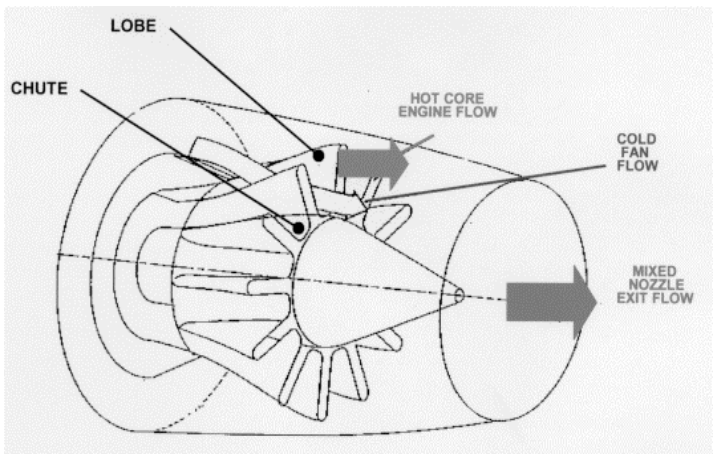
MODIFIED "MGB" CODE, now called "MGBK"

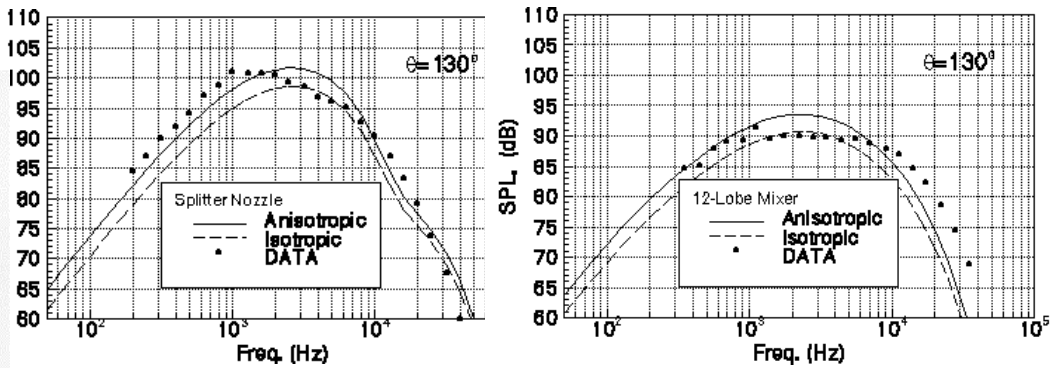
Combines CFD solutions with modeling of noise sources to predict far-field acoustics

- **Small-scale turbulence noise**
- **External mixing noise only**
- **Accounts for both self and shear noise**
- **Non-isotropic turbulence**
- **Can be extended to a 3D geometry (assumes flow is locally axisymmetric)**

Splitter Nozzle **12-Lobe Mixer**







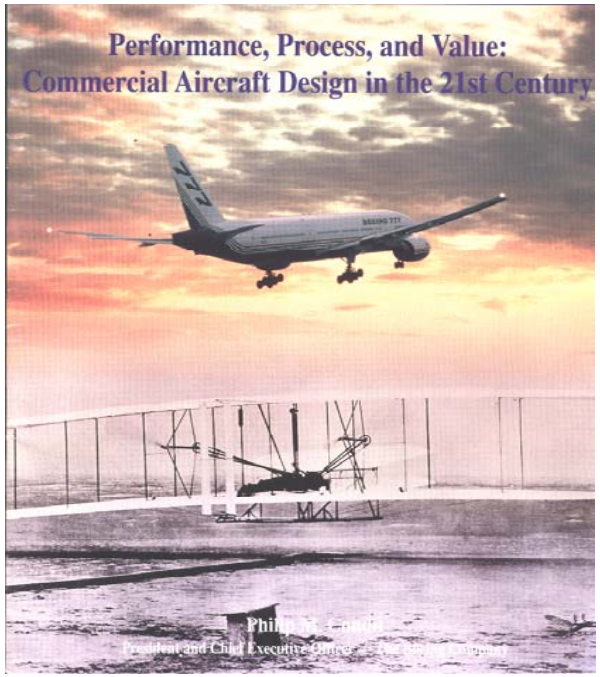
Isotropy: $L_2 / L_1 = 1, \quad \overline{u_2^2} / \overline{u_1^2} = 1$

Anisotropy: $L_2 / L_1 = 0.8, \quad \overline{u_2^2} / \overline{u_1^2} = 0.7$

Future Directions

1996 Wright Brothers Lectureship in Aeronautics

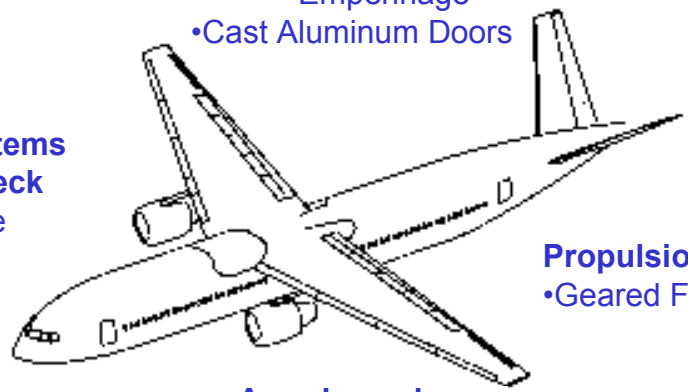
by Philip M. Condit, The Boeing Company, October 22, 1996



2016 Subsonic Airplane

Structure & Materials
- Low Temperature Graphite Composite:
  - Fuselage
  - Wing
  - Empennage
- Cast Aluminum Doors

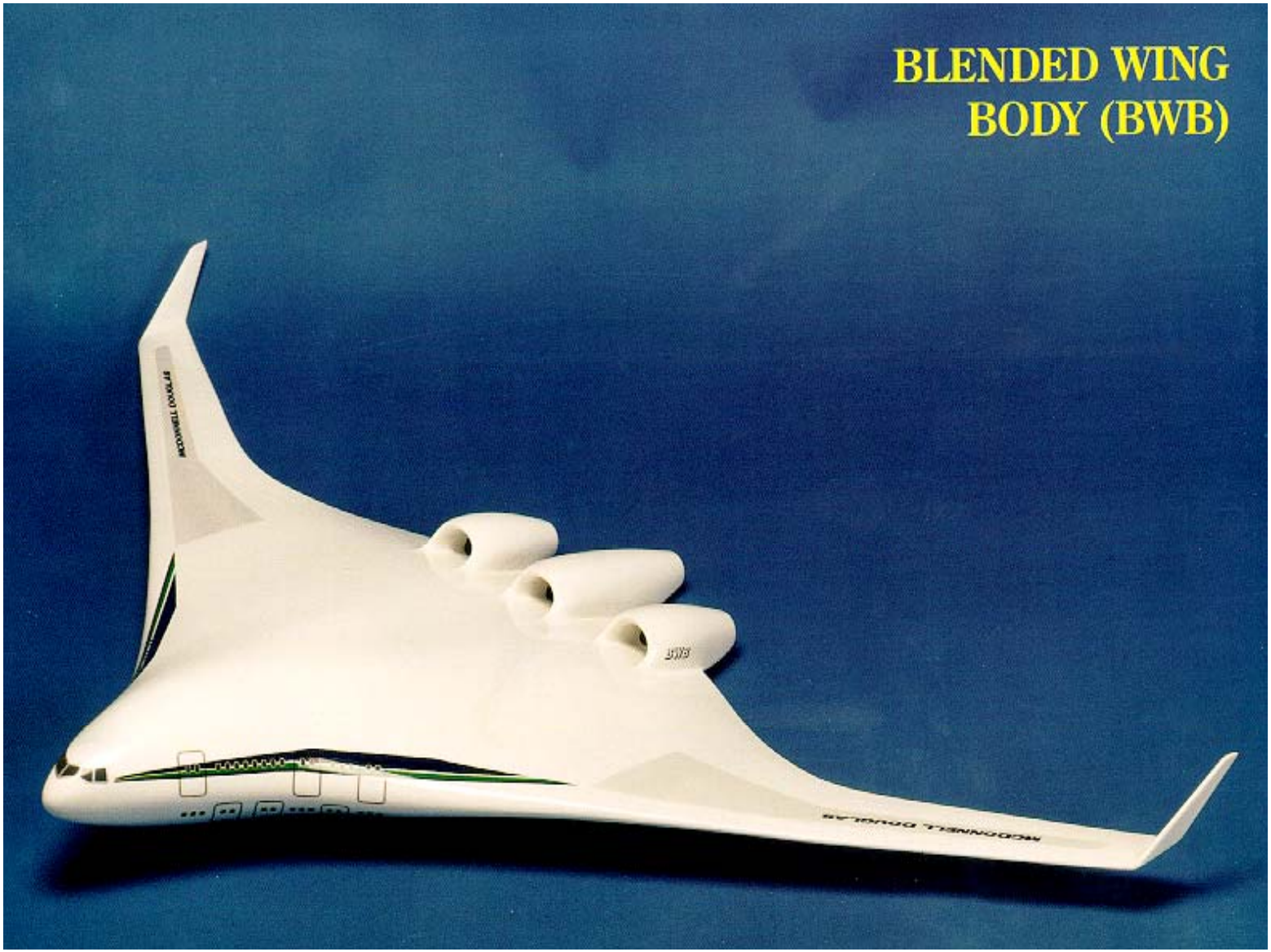
Flight Systems & Flight Deck
- Fly-by-wire



Propulsion System
- Geared Fan Engines

Aerodynamics
- Slotted Cruise Airfoil
- Natural Laminar Flow

"Ultra-high-bypass-ratio engines [to] reduce fuel consumption, engine maintenance, and community noise. It might be possible to reduce community noise by 10 dB, thus making airplane noise a non-issue at airports."


BLENDED WING
BODY (BWB)